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# Microscopic technique to determine various wear modes of used engine oil

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ABSTRACT

Engine oil is an important and the most essential part of machine system. Oil monitoring is a tool to determine lubricant useful life. It can be either performance testing or oil condition monitoring. Knowledge of the system's failure modes is essential for cost-effective oil monitoring. Contamination occurs by mating contact inside the engine chamber. In the present work used $CH_4$15W40 engine oil were monitored under bichromatic microscope to observe the contamination and surfaces wear micrograph. According to the observation, rubbing, cutting, fatigue, corrosion, abrasive and scuffing wear modes were observed.



## 1. Introduction

Lubricant inspection and testing has been used to diagnose the internal condition of oil components and provide valuable information about lubricant serviceability. A large numbers of tests such as FTIR, wear debris analyser and magnetic plugs were developed to assess the physical properties of lubricant with their contaminants level. Oil monitoring techniques were used by many researchers like three line method [1–4], ferrography [5], grey system theory [6,7] and FTIR [8]. Oil analysis is the most widely accepted form of proactive maintenance. It is an integral part of the maintenance plan for various industries. Any equipment that has a lubricating system is suitable for oil analysis. Oil monitoring can be used to diagnose the tribological failures. The tribological failures are identified due to quality changes of the lubricants and wear particles analysis. The monitoring of wear condition is a complex phenomenon. A large variety of methods have been developed to quantify the presence of pollutant in the oil caused by engine wear [9]. Its application includes automobile, construction, Power Plant, manufacturing plants, trucking companies, marine, mining industry, aircraft, refrigeration systems, processing, medical fields and chemical plants.

The present work describes a ferrographic method to evaluate wear conditions in $CH_4$15W40 engine oil. The methodology proposed uses ferrography wear debris measurement data that takes into account lubricant operating condition affecting wear concentration measurement. Various source of oil contamination were also listed in Table 2.

## 2. Material and methods

$CH_4$15W40 high quality diesel engine oils designed for lubrication of units burning low sulphur distillate fuels and designed with the high detergent additive system. These oils have excellent Total Base Number (TBN) retention to ensure protection throughout the oil drain period. It has enhanced protection against corrosion and wear.

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**Table 1**
Properties of $CH_4$15W40 oil.

| Properties | Determined values |
|---|---|
| Density, kg/L 15.5 C | 0.870 |
| Kinematic viscosity @ 100 °C, cSt | 14.0–16.0 |
| Viscosity index | 130 |
| Flash point, COC | 220 °C |
| Pour point, °C | −27 °C |
| TBN, mgKOH/g | 9.0 |

$CH_4$15W40 oils provide reliable all-year round performance in the application for which they intended [10]. Usually $CH_4$15W40 oils use in heavy long distance trucking and constant speed on road operations. The various properties of fresh engine oil listed in Table 1.

### 2.1. Analytical ferrography

Analytical ferrography technique is useful to analyze the wear particles present in the used oil. Large ferrous particles penetrate along the length of the ferrogram. This technique involves passing a volume of fluid over a slid which is supported over a magnetic field. Permanent magnets arranged to create varying field strength over the length of the substrate. This varying strength causes wear debris to precipitate distribution with respect to size over ferrogram. Debris deposited over slid serves as an excellent media for optical analysis of the composite wear particulates. After the ferrography, slid were taken out for microscopic analysis.

A bichromatic microscope used to determine wear characteristic. It is equipped with reflected and transmitted light sources in order to make ferrogram illuminated from above and below the microscope stage. This used to view and examine ferrograms made with the Spectro. A green filter is used in the transmitted light path and a red filter is used in the reflected light path, this is referred to as bichromatic illumination in the practice of ferrography.

## 3. Result and discussion

Microscopic observation of used $CH_4$15W40 engine oil has been demonstrated in Fig. 1(a)–(f). Fig. 1(a) shows rubbing wear particles those are platelets from the shear mixed layer which exhibit super ductility generated by a diesel engine. Largest particle present in the rubbing wear to be of 10 μm. In this wearing process the opposing surfaces are of same hardness. Maximum particle size for rubbing wear is 15 μm. Break in period was also observed, these ridges on the wear surface gets flattened and form cornices along the ridge peaks. These components having machined surface finish. Cutting wear Fig. 1(b) appears due to penetration result of one surface to the other. Abrasive wear particles trapped in a soft surface, penetrate the opposing surface generating cutting wear particles. Cutting wear particles are long large stripes in nature. The rocks like particles are actual contaminants, all other material on slid are metallic cutting wear. In this wear particle size may vary in range of 2–5 μm wide, and 25–100 μm long. The cutting wear is demonstrated as all low alloys steel. Fatigue spall Fig. 1(c) generated from the stressed surface as a pit with a maximum size of 100 μm. Spherical fatigue generated in rolling bearing fatigue crack. The spheres are generally 3 μm in diameter. High ratio of large particle to small particle is typical rolling fatigue. This fatigue generates from crack initiation to crack growth and at last these cracks come closer to grain boundary in the form of spallation. A large number of wear particles contributed by nearby bearing component. Fig. 1(c) displays the irregular shape and size of a particle that can generate rolling fatigue [11]. Scuffing wear Fig. 1(d) particles are created by the sliding of a two smooth surface over each other. This wear particle is a smooth metal flake with no edge relief. These particles can be thin in nature but quite large in 2D. Scuffing is associated with high speed, high load lubricated contacts particularly with cams, cylinder bores and gears. Corrosive wear is indicated by a heavy deposit of fine particle at the exit end of the slid Fig. 1(e). Corrosion wear failure resulting from dynamic contact between two surfaces such as abrasion and erosion of particles in interspaces. Erosion is due to the continuous impingement of tiny particles at the surface. Fig. 1(f) shows abrasive wear phenomenon as a hard rough surface slides across a softer surface. The type of contact determines the mode of abrasive wear; it may two body or three body abrasion. Two body abrasion wear takes place when the grits or hard particles remove material from the opposite surface due to the action of ploughing or cutting operation. Three-body wear occurs when the particles are trapped between the two consequent materials and are free to roll and slide down a surface. Some of the particles present in the oil are listed in Table 2 [12].

**Table 2**
Metal source present in oil sample.

| Elements | Contaminant sources |
|---|---|
| Iron (Fe) | Cylinder liners, crankshafts, gears, shafts, anti-friction bearings |
| Chromium (Cr) | Cylinder liners, rings, shafts, anti-friction bearings, coatings |
| Vanadium (V) | Valves |
| Titanium (Ti) | Springs, valves, |
| Nickel (Ni) | Anti-friction bearings, gears, valve and valve guides |
| Molybdenum (Mo) | Piston rings, synchro rings, oil additives, greases |
| Tin (Sn) | Plain bearings, piston flashing |
| Silicon (Si) | Dirt entry, oil additives, internal coolant leak, greases, pistons |

Used oil analysis is known to be every effective tool for health monitoring and as a proactive maintenance technology. The lubricating oil particles carry detailed information about the condition of the machine element which is deduced from particle shape, size, concentration and composition. Particle characteristic should be specific so that correct wear mode can be identified easily and corrective action should be taken as soon as possible to reduce the down time of machine. Generally two types of particles identified through ferrography, metallic and non metallic. Metallic particles normally generated from gear, bearings [11] or couplings, and non-metallic particles come from seals, those are made of synthetic materials. Used oil analysis helped in maximizing the mean time between failures of the machinery and cost saving

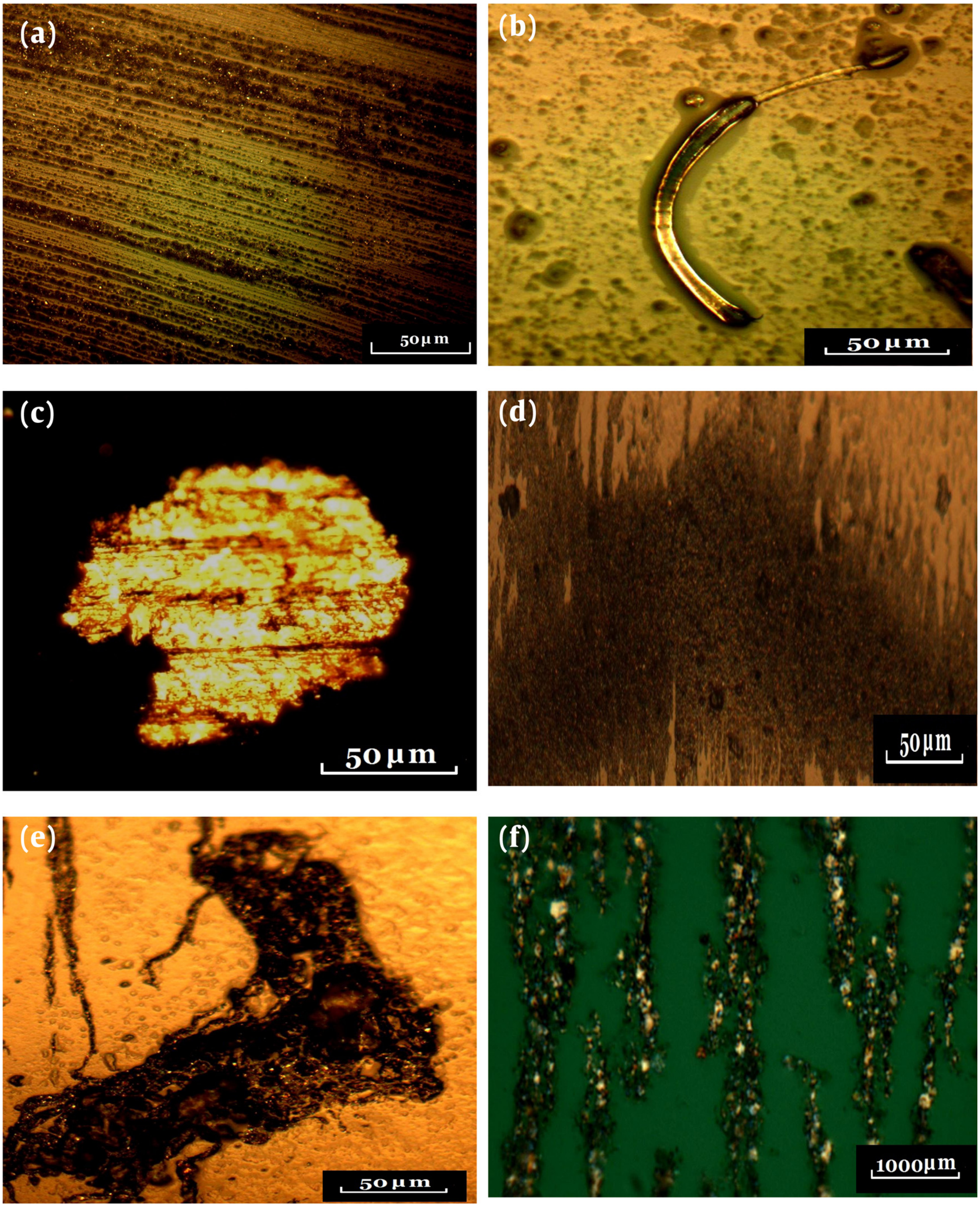


**Fig. 1.** (a) Rubbing wear, (b) cutting wear, (c) fatigue wear, (d) scuffing wear, (e) corrosive wear, and (f) abrasive wear.

in replacement of lube oils. The ferrogram attracts ferrous particles from oil. Magnetic field causes the magnetic particles align themselves along the length of the slide. The largest particles were deposited at the entry zone. Non-ferrous particles and other contaminants are unaffected by the magnetic field and travels downstream. These particles are randomly deposited across the length of the slide.

## 4. Conclusion and recommendation

A morphological feature of wear particles is an important quantitative aspect of wear particle image analysis. Wear measurement depends on tribological features at interspaces. Image analysis technique with microscopic is the best way to recognize the main cause of the particle generation. Contaminant added to the lubricant play an important role in wear processes. Hard particle accelerate the wear processes whereas soft particle decreases the wear rate. This technique is quiet useful to alerts an operator earlier than any other damage symptoms. A corrective action must be taken to overcome wear problems. Proper lubrication system is required to reduce friction at its minimum because insufficient lubrication generates high friction which increases further wear rate. High friction affects the component performance and it starts to consume more power for the same output. Periodically change of lubricating oil is suggested. It is highly recommended to change the oil immediately as soon as first wear particles is identified.

## Conflict of interest

The author declares no competing financial interests.

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